Proposal

Economic Valuation of Increased Water Supply Reliability and Trading Opportunities in Westside Agriculture

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Objective: This project will evaluate the economic impacts of increased water supply reliability and expanded water trading opportunities on growers in the western portion of the San Joaquin Valley. The project will quantify the impact of changes in reliability on investment behavior and water use, measure growers' willingness to pay for additional reliability, and examine how expanded water trading opportunities within agriculture affect growers' valuations of supply reliability.

Method: We propose to construct a dynamic, stochastic model of agricultural water use that reflects inter-year variations in surface water supplies and is tailored to growing conditions in the west side of the San Joaquin Valley. Three types of entities will be considered: exchange contractors, CVP service contractors and SWP contractors. The model will be used to measure the change in land allocation, irrigation technology, choice, groundwater use and producer welfare resulting from changes in water supply conditions. Water supply has two dimensions: changes in the mean and variance of supplies available to individual farms, and changes in water trading possibilities among growers.

Our approach employs option value theory as developed in the finance literature. Due to the uncertainty of future water supplies and the quasi-irreversible nature of investment in modern irrigation technology and perennial crops, the option to delay investment has value. By waiting to invest, a farm can observe whether water prices increase or decrease before committing to a sunk investment cost. One practical advantage of this approach is that it expresses investment decision rules in terms of both the mean and variance of future water supplies. This feature is important since an important economic question concerning CALFED is growers' valuation of enhanced supply reliability. Another important feature of this type of model is that it explains actual grower investment decisions better than traditional models that compare expected net benefits to costs. In particular, the theory predicts that investment will occur in waves, and is prompted by periods of crisis or extreme scarcity. Traditional theory predicts much smoother responses to changes in economic conditions, and assumes that disinvestment is as easy as investment.

Theory: Comparison with Traditional Approach
Consider a simple version of our approach that illustrates the method and highlights the contrast between our approach and the traditional theory. For purposes of this discussion, we examine an individual farm that desires to minimize the cost of producing a given

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output by choosing its irrigation technology and the amount of water to apply to its crop. Suppose that the farm initially produces with the traditional irrigation technology, and it has the option to invest in modern irrigation technology that is more efficient. In order to switch technologies, the farm must pay an irreversible investment cost. This cost includes the expense of designing the system and investing in the new infrastructure (*e.g.* pipes, filters and drainage equipment). In addition it may include human capital costs associated with training workers to use the new irrigation system. Once the farm switches technologies, it is assumed to use the modern technology forever. The farm's water supply and the market price of water are stochastic. The presentation here assumes that the farm can trade water in a competitive market with no transaction costs. The farm's trading behavior is assumed to have no impact on the market price of water.

The farm's minimization problem is

$$\begin{aligned} & c(p,s) = \min px_i + w_i a_i + k_i \\ (1) \qquad & s.t.\ y \le f(h_i a_i) \\ & x_i = a_i - s. \end{aligned}$$

where p is the stochastic market price of water, and x_i is the amount of water the farm trades in the market when using technology i. w_i and k_i are the marginal and fixed costs per acre of using technology i. Due to greater energy and management costs, the modern technology is assumed to be more expensive to operate than the traditional technology. Thus, $w_2 > w_1$ and $k_2 > k_1$. a_i is the quantity of water (in acre-feet) that the farm applies to an acre of crops, and y is the required output per acre determined by the farm's long-term contract. h_i is the irrigation efficiency of technology i ($0 < h_i < 1$), and s is the farm's stochastic initial allocation of water. Since the farm's initial supply is stochastic, the amount it trades in the market is also stochastic. x_i is greater (less) than zero if the farm buys (sells) water in the market.

The farm's minimization problem can be rewritten as

$$(2) \qquad c(p,s) = \min_a p(a_i - s) + w_i a_i + k_i + \lambda(y - f(h_i a_i)).$$

Let a_i^* be the minimum water input required to produce y with technology i. Since the modern technology is more efficient than the traditional technology, $a_2^* < a_1^*$. Given that the farm must produce y, its cost function with technology i at time t is

$$(3) \qquad c(p,s;\phi_i) = p(a_i^* - s) + w_i a_i^* + k_i,$$

where ϕ_i is the vector of parameters (w_i, k_i, h_i) associated with technology i. If a farm receives a large initial allocation of water and sells its surplus in the market, its cost at t may be negative. This will be true if the revenue from water sales is greater than the cost of irrigation.

The aggregate annual supply of surface water to a given farm fluctuates stochastically primarily due to inter-year variations in weather. The model represents the stochastic supply process by a geometric Brownian motion

$$(4) \qquad ds = \alpha_s s dt + \sigma_s s dz_s,$$

where $s(t)$ is in units of acre-feet per acre. α_s is the instantaneous drift rate of the supply process and σ_s is the instantaneous variance rate.

Assumes that the farm receives its water allocation for free. The final version of the model will of course relax this specification. Assume also that the farm does not have access to groundwater; this feature will also be relaxed in the final version. The farm can smooth its water supply by buying or selling water in the market. The market is a spot market in which the farm can buy or sell a given number of acre-feet for use at time *t*. It is not a market in long-term water rights. If the farm were to buy long-term water rights, expected future values of *s* would change.

The market price of water, in dollars per acre-foot, is represented by a geometric Brownian motion with positive drift

(5) $$dp = \alpha_p p dt + \sigma_p p dz_p, \quad E[dz_s dz_p] = \gamma dt, \quad \gamma < 0.$$

α_p is the expected instantaneous drift rate of the price process and σ_p is the expected instantaneous variance rate. To the extent that an individual farm's supply mirrors the aggregate supply, *s* and *p* will be negatively correlated.

The farm's decision to invest in the modern irrigation technology depends on the tradeoff between the expected present value of the investment and the fixed cost of the investment. If the farm switches from the traditional to the modern technology, it must pay a one-time per-acre fixed cost of *I*. To calculate the expected present value of the investment, consider first the value of the investment at a given *t*. The value at *t* is the farm's cost savings with the modern technology

(6) $$v(p) = c(p, s; \phi_1) - c(p, s; \phi_2).$$

Substituting in and simplifying, the cost savings are

(7) $$v(p) = p(a_1^* - a_2^*) - (w_2 a_2^* + k_2 - w_1 a_1^* - k_1).$$

Defining $a^* = a_1^* - a_2^*$ and $q = w_2 a_2^* + k_2 - w_1 a_1^* - k_1$, the value of the investment is at *t* can be written concisely as

(8) $$v(p) = pa^* - q.$$

pa^* is the market value of the water conserved with the modern technology, and q is the increase in user cost associated with the modern technology. From Equation (5), one can see that the cost of producing with either technology depends on *s*. However, since the farm receives the value of its initial water supply, *ps*, with either technology, the value of the investment is independent of *s*. This result is dependent on the assumption of a frictionless water market. If a farm did not have access to a market, or if it must incur positive transaction costs in order to trade, its investment decision would depend on *s*.

The farm's investment decision depends on the expected net present value of the cost reduction over all future time periods

(9) $$V(p) = E\int_0^\infty p_t a^* e^{-\rho t} dt - \int_0^\infty q e^{-rt} dt.$$

Since p is stochastic, it is discounted by the risk-adjusted rate ρ. Since q is deterministic, it is discounted by the risk free interest rate r. If the initial water price is p then $E[p_t] = pe^{\alpha t}$. Thus,

$$(10) \quad V(p) = \int_0^\infty pa^* e^{-(\rho-\alpha)t} dt - \int_0^\infty q e^{-rt} dt.$$

Since pa^* follows a geometric Brownian motion with drift rate α_p, it must be discounted by the modified rate $\rho - \alpha_p$. The expected net present value simplifies to

$$(11) \quad V(p) = \frac{pa^*}{\delta} - \frac{q}{r},$$

where $\delta = \rho - \alpha_p$.

In the traditional Marshallian investment model, the farm should invest if $V(p) \geq I$, that is if the expected net present value of the investment is greater than or equal to the fixed cost of investment. Equivalently, at $t = 0$ the farm chooses the technology that minimizes its expected net present costs

$$(12) \quad C(p, s; \phi_i) = \min\left(\frac{pa_1^*}{\delta} - \frac{ps}{\delta'} + \frac{q_1}{r}, \; \frac{pa_2^*}{\delta} - \frac{ps}{\delta'} + \frac{q_2}{r} + I \right).$$

It can use the traditional technology or pay I in order to use the modern technology. The farm trades off the water conservation benefits of the modern technology against the increased operating costs of the modern technology and the required investment cost. In the Marshallian model, the farm will choose the modern technology if the price of water is greater than or equal to $\tilde{p}$, where

$$(13) \quad \tilde{p} = \frac{\delta}{a^*}\left(I + \frac{q}{r} \right).$$

As intuition would suggest, the farm is more likely to choose the modern technology (*i.e.* $\tilde{p}$ falls) as the water savings a^* associated with the modern technology increase.[1] Conversely, the farm is less likely to invest as the discount rate used to value the investment δ increases, or as either the fixed cost of investment I or the additional operating cost q/r increases.

In practice, farms often require that the benefits of investment exceed the costs of investment by a positive hurdle rate in order to invest. The Marshallian model ignores key aspects of a farm's investment decision that may make the farm hesitant to invest. First, it does not account for the effects of uncertainty on a farm's investment decision. It predicts that a farm's investment rule (invest if p rises to $\tilde{p}$) is independent of the volatility of p. Second, the Marshallian model does not consider the irreversible nature of an investment in modern irrigation technology. If a farm invests in drip irrigation and then water prices fall, thus lowering the value of the investment, the farm cannot easily

[1] Note that q is a negative function of a^*. Thus, in addition to the direct effect of an increase in a^*, the decrease in q associated with an increase in a^* also reduces $\tilde{p}$.

recover its investment costs. Third, it assumes that a farm faces a now-or-never investment decision. It ignores the fact that, due to the farm's access to a water market, it has the option to wait and invest at a later date. We will develop a modified Dixit-Pindyck investment rule that accounts for uncertainty, irreversibility and the option to wait.

Because of the flexibility provided by the water market, the farm does not have to make a now-or-never investment decision as suggested by Equation (12) of the Marshallian model. If the farm's water supply falls short, and the price of water is low, it may choose to buy water in the market instead of investing in modern irrigation technology. The farm has the option to invest in the modern technology if the price of water should rise in the future. Given this flexibility, the farm's expected net present costs at $t = 0$ are

$$(14) \qquad C(p,s;\phi_i) = \frac{pa_1^*}{\delta} - \frac{ps}{\delta'} + \frac{q_1}{r} - F(p),$$

where $F(p)$ represents the value of the farm's option to invest in the modern technology. Over low price ranges, the value of the investment $V(p)$ is less than the fixed cost of investment I. Therefore the option to switch technologies is "out of the money," and the farm will not exercise its option to invest. At a sufficiently high water price, however, the option to switch technologies will become "in the money," and the farm will exercise its option to invest. The farm trades off the benefit associated with waiting for more information before committing to a sunk investment cost against the opportunity cost of waiting to invest.

Dynamic optimization techniques can be used to solve for the farm's optimal investment rule. Define $\bar{p}$ to be the price that triggers investment. In the region $(0,\bar{p})$, in which the farm holds onto its opportunity to invest, the Bellman equation is

$$(15) \qquad \rho F(p)dt = E[dF(p)].$$

The Bellman Equation states that over the interval dt, the return on the investment opportunity $\rho F dt$ is its expected rate of capital appreciation $E[dF(p)]$.

Using Ito's Lemma, one can expand the right-hand side of Equation (15) and show that p satisfies the following differential equation

$$(16) \qquad \tfrac{1}{2}\sigma_p^2 p^2 F''(p) + \alpha_p p F'(p) - \rho F(p) = 0,$$

subject to the boundary conditions

$$(17.1) \qquad F(0) = 0$$

$$(17.2) \qquad F(\bar{p}) = V(\bar{p}) - I$$

$$(17.3) \qquad F'(\bar{p}) = V'(\bar{p}).$$

Since the *difference* in profit between the modern and traditional technologies is independent of s, the value of the option to invest $F(p)$ satisfies an ordinary differential equation in p. Equation (17.1) states that when the price of water is zero, the option to invest is worthless. Intuitively, the farm has no incentive to pay to conserve water if it is free. Equation (17.2) is known as the value-matching condition. It states that the value of the option should equal the expected present value of the investment less the fixed cost of investment at the threshold. Equation (17.3) is known as the smooth-pasting condition. It states that the change in the value of the option associated with an increase in p should equal the change in the expected present value of the investment at the threshold. The threshold water price $\overline{p}$ that triggers investment must be found as part of the solution.

Solving Equation (16) subject to Equations (17.1-17.3), the general solution for the value of the option reduces to

(18) $F(p) = B_1 p^{\beta_1}$.

β_1 is the positive root of the fundamental quadratic

(19) $\frac{1}{2}\sigma_p{}^2\beta(\beta-1)+(\rho-\delta)\beta-\rho=0$,

and the constant B_1 must be determined as part of the solution. Substituting in Equations (11) and (18), the value-matching and smooth-pasting conditions evaluated at $\overline{p}$ are

(20.1) $$B_1\overline{p}^{\beta_1} = \left(\frac{\overline{p}a^*}{\delta}-\frac{q}{r}\right)-I$$

(20.2) $$\beta_1 B_1 \overline{p}^{\beta_1-1} = \frac{a^*}{\delta}.$$

Combining (20.1) and (20.2), one can solve for the threshold of investment

(21) $$\frac{\overline{p}a^*}{\delta} = \left(\frac{\beta_1}{\beta_1-1}\right)\left(\frac{q}{r}+I\right).$$

The threshold condition can be rewritten as

(22) $$\hat{V}(\overline{p}) = \left(\frac{\beta_1}{\beta_1-1}\right)\hat{I},$$

where $\hat{I} = q/r + I$ is the total cost of the investment and $\hat{V}(p) = pa^*/\delta$ is the expected value of the investment. Since $\beta_1 > 1$, the condition states that expected value of the investment must be greater than the total investment cost at the threshold. $\beta_1/\beta_1 - 1$ is the option-value wedge or hurdle rate. By rearranging Equation (21), one can solve explicitly for the threshold price of investment

(23) $$\overline{p} = \left(\frac{\beta_1}{\beta_1-1}\right)\frac{\delta}{a^*}\hat{I}.$$

For $p < \overline{p}$ the farm holds on to its option to invest and uses the traditional technology, and for $p \geq \overline{p}$ the farm exercises its option and produces with the modern technology. Note that $\overline{p} = (\beta_1/\beta_1 - 1)\,\tilde{p}$, where $\tilde{p}$ was the threshold price of the Marshallian model. When one accounts for uncertainty, irreversibility and the option to wait, the farm requires a higher price before it is willing to invest.

We can now show how changes in reliability affect investment. As σ_p rises, the hurdle rate increases.[2] Thus, the difference between the revised investment rule and the Marshallian rule is greater the higher the uncertainty. Due to the increase in the hurdle rate, $\hat{V}(\bar{p})$ and $\bar{p}$ both increase. Intuitively, if future water prices are more uncertain, the value of the option to invest is greater and the farm will require a higher investment value before it is willing to invest. Since the value of its investment increases as the price of water increases, the farm will wait until the price climbs higher before investing.

If the expected value of future water prices is increasing $\left(0 < \alpha_p < \rho\right)$,[3] there may be a value to waiting even if there is no uncertainty. If the investment is not currently profitable, eventually $\hat{V}(p)$ will exceed $\hat{I}$. Also, even if $\hat{V}(p) \geq \hat{I}$ initially it may be better to wait rather than invest now because, when $\alpha_p > 0$ the investment cost is discounted at a higher rate than the payoff. Since there is no uncertainty, one can solve for *T*, the time at which it is optimal to invest. Given an initial price of p, the price of water at *t* will be $p(t) = pe^{\alpha t}$. Substituting $p(t)$ into the value function gives

$$\text{(24)} \quad \hat{V}(p(t)) = \frac{a^* pe^{\alpha t}}{\rho - \alpha_p} = \hat{V}_0 e^{\alpha t}$$

The value of the investment opportunity given that the farm invests at some future *t* is

$$\text{(25)} \quad F(p) = \left(\hat{V}_0 e^{\alpha t} - \hat{I}\right) e^{-\rho t}.$$

Notice that the farm has an incentive to delay investment because in present value terms the cost of the investment decreases by a factor of $e^{-\rho t}$ whereas the payoff is reduced by the smaller factor of $e^{-(\rho-\alpha)t}$.

Differentiating Equation (25) with respect to *t*, and setting the expression equal to zero, one can solve for the optimal time of investment

$$\text{(26)} \quad T = \max\left\{\frac{1}{\alpha}\ln\left(\frac{\rho}{\delta}\frac{\hat{I}}{\hat{V}_0}\right),\ 0\right\}.$$[4]

From the expression for *T* one can deduce that it is optimal to invest immediately if $\hat{V}(p) \geq \frac{\rho}{\delta}\hat{I}$. Otherwise the farm should wait before investing.

Figure 1 illustrates how the farm's investment strategy changes in response to changes in the level of water price uncertainty. The following parameter values are used in the baseline case.

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[2] This can be seen by totally differentiating Equation (19). As σ_p increases, β_1 decreases and therefore $\beta_1/(\beta_1 - 1)$ increases.

[3] $\alpha_p < \rho$ is required for convergence.

[4] The second order condition is $\alpha_p > 0$.

Table 1

$\sigma_p = 0.15$	$\alpha_p = 0.06$
$r = 0.05$	$I = \$800 / acre$
$\rho = 0.12$	$q = \$20 / AF$
$\delta = \rho - \alpha_p = 0.06$	$a^* = 1.5\, AF$

The parameters are representative of actual values. Caswell *et. al.* estimate that, for cotton growers in the San Joaquin Valley, water use per acre varies between 4.17 and 3.69 AF with furrow irrigation, between 3.13 and 2.79 AF with sprinkler irrigation, and between 2.63 and 2.41 AF with drip irrigation. Using their upper estimates, if a farm switched from furrow to drip technology, a^* would equal 1.54 AF ($a^* = 4.17 - 2.63$).

The straight line shows the expected net present value of the investment $\hat{V}(p) - \hat{I}$ as a function of p. The expected net present value equals zero when p = \$48 per AF. According to the Marshallian investment rule, the farm should invest if $p \geq$ \$48 per AF. The curved lines show the value of the option to invest $F(p)$ as a function of p for three values of σ_p. The points of tangency between $F(p)$ and $\hat{V}(p) - \hat{I}$ give the threshold price $\bar{p}$ for each positive level of σ_p. In the baseline case, $\bar{p}$ equals \$112 per AF and $\hat{V}(\bar{p}) - \hat{I}$ equals \$1594 per acre. When σ_p is reduced to 0.05, $\bar{p}$ falls to \$98 per AF and $\hat{V}(\bar{p}) - \hat{I}$ falls to \$1249 per acre. When σ_p is increased to 0.25, $\bar{p}$ increases to \$135 per AF and $\hat{V}(\bar{p}) - \hat{I}$ increases to \$2171 per acre. *Figure* 1 illustrates the sensitivity of both $\bar{p}$ and $\hat{V}(\bar{p}) - \hat{I}$ to the level of water price uncertainty. When $\sigma_p = 0.25$, the farm should wait until the expected value of the investment $\hat{V}(\bar{p})$ is 2.8 times greater than the cost $\hat{I}$ before it invests. This example demonstrates that policies that reduce uncertainty may promote investment.

Data

The theoretical model will be tailored to conditions in the west side of the San Joaquin Valley. Information on the base land allocation among crop groups, environmental (especially soil and weather) conditions, crop yields, water supplies, irrigation technology choice and groundwater availability will be collected. Much of this information is currently available from the CARM/CVPM database as well as from other research projects at UC Berkeley and UC Davis (e.g., the Financial Incentives Challenge Grant). Gaps in the existing database will be filled through interviews with USBR, DWR and water district personnel, and by examining other databases. We should note that we will strive to be consistent with the CVPM database whenever possible. In this way, we will be able to isolate as accurately as possible the source of possible differences in the results of CVPM and our model.

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Our effort will rely on water supply information provided by DWR or the CALFED modeling team. In particular, we will need to know how construction of various storage facilities will affect the mean and variance of aggregate and individual district supplies.

Relation to Existing Models: One important feature of the modeling approach proposed here is that it emphasizes the relation between trading and durable investments as a means of coping with inter-year fluctuations in water price and availability. While irreversibility is becoming a standard model of the economics of investment, there have been relatively few applications of the framework to environmental problems. Hassett and Metcalf employ the option value approach in a technology switching model applied to residential energy conservation investments. They find that consumers' responses to investment tax credits were very low. If consumers were making their decisions based on net present value theory, they had to have been using extremely high discount rates. Hassett and Metcalf develop a model in which investments are irreversible and the price of heating fuels fluctuates randomly over time. Given the irreversibility and uncertainty of investments, the model predicts that individuals will wait to invest until the return is significantly greater than the investment cost. The household investment data support their model. They simulate the effect of an investment tax credit and find that, if uncertainty is ignored, the effect of the tax credit is significant. However, when uncertainty is taken into account, the tax credit has very little impact.

Herbelot employs the option value approach in an analysis of electric utilities' efforts to comply with $S0_2$ emissions regulations. An electric utility can comply with the regulations by purchasing permits from other utilities, or by switching to a low-sulfur fuel or installing scrubbers. If the utility switches fuels it must pay a sunk cost to retrofit the plant, and if it installs scrubbers it must also pay a sunk capital cost. In addition, the price of emission allowances and the price premium on low-sulfur fuel fluctuate stochastically. Herbelot shows that the utility may choose to purchase emission allowances, even if the expected present value of compliance is higher with the allowances, because of the flexibility they provide. Even if the utility does not decide to switch fuels or install scrubbers, Herbelot argues that the utility's true compliance cost is lower because it has the *option* to switch fuels or install scrubbers.

There is an extensive literature in irrigation technology adoption; however it does not address the effects of uncertainty, irreversibility and the option to wait on a farm's investment strategy. The traditional Marshallian models of investment used in the literature predict that a farm will invest when the expected present value of investment equals the cost of investment. A key result of the dynamic, stochastic approach proposed here is that a farm will not invest in the modern technology until the expected present value of investment *exceeds* the cost of investment by a potentially large hurdle rate. This decision rule causes investment to be more "lumpy" than the traditional model.

The investment rule implied by considering irreversibility may be more consistent with observed behavior than the traditional Marshallian rule. Zilberman *et al* examined the diffusion of drip and micro-sprinkler irrigation in California and found that farms wait until the return is significantly greater than the cost before investing in modern irrigation technologies. From 1982-86 adoption rates were slow even though modern technologies appeared to be cost effective in many areas. The five-year drought from 1987-91 drove returns sufficiently above investment costs and triggered widespread adoption. For example, the number of acres of citrus cultivated under drip irrigation almost doubles during the last years of the drought.

Another implication of our approach is that the introduction of a water market may decrease technology adoption incentives for some farms. This result contradicts the common view in the literature that water markets will increase technology adoption rates. If a farm is a net demander of water, it can postpone irrigation technology investments if it has the option to purchase water in a market. Only when a farm is a net seller, will the introduction of a water market increase its incentive to adopt modern irrigation technology.

Personnel: The project will be carried out under the auspices of the Center for Sustainable Resource Development at UC Berkeley's College of Natural Resources. Dr. David Sunding of UC Berkeley will serve as the principal investigator. He will be the point of contact for both the CALFED team and stakeholder interests. Dr. Sunding is also the principal investigator on a project developing an electronic water trading system in the San Luis & Delta-Mendota Water Authority. Dr. David Zilberman will be heavily involved in the modeling aspects of the project, particularly those related to the design of the empirical model. Dr. Janis Olmstead of the Colorado School of Mines will also be involved in modeling issues. In her UC Berkeley dissertation, she developed some of the basic results on irrigation technology investment and supply reliability. Dr. Olmstead has also been involved in implementing a water trading system in Westlands Water District. Dr. Cyrus Ramezani of UC Berkeley's Haas School of Business will consult on some of the theoretical issues related to the technology and land allocation aspects of the model. He is an expert in finance and capital investment theory, and has recently written some important papers on the subject of irreversibility in environmental economics. Dr. Richard Howitt of UC Davis has a close working relationship to Drs. Sunding and Zilberman, and will consult on model development. He is an expert in agricultural water use, and has also written recently on the subject of sunk costs and investment behavior. This core team will be assisted by two UC Berkeley doctoral students who will be responsible for data collection, programming and running the model. The final report will be written by Drs. Sunding and Zilberman.

Key input regarding model specification and policy scenarios will be provided by an advisory panel composed of economists selected by various stakeholder groups. There will be 4-8 individuals comprising this panel, and all members must have appropriate technical expertise (ideally, a Ph.D in economics or a related discipline). Dr. Sunding will chair this advisory panel, and will take steps to ensure that diverse viewpoints are represented in the final report. The information flow will be in two directions: advisory group members will have an opportunity to voice their views regarding assumptions, data and policy scenarios, and project researchers will have an opportunity to educate stakeholder groups through their representatives on the board. Again, the goal of this panel is primarily technical, not political, and advisory group input will emphasize modeling issues to ensure that the final product meets the highest professional standards. Final control of the project output rests with UC researchers.

At the request of the USEPA, the advisory board will also consider issues related to short-term economic analysis of CALFED alternatives. The budget presented below includes a small amount of funds for UC personnel to prepare for and attend these meetings; as necessary, they will devote extra time at no cost. Advisory group meetings will be held at UC Berkeley.

Timeline: The project will commence upon authorization of funding; all key personnel are ready to start work immediately. Data collection and conceptual model refinement will occur over the summer. Both graduate students will work full-time during this period. The empirical model will be constructed during September, and there is some possibility that very preliminary results will be available by the end of September. More realistically, construction and verification of the empirical model will be complete by February, at which time many model results will be available, and the final report will be completed by the end of May, 1999. Scholarly articles will be submitted for publication in peer-reviewed journals during and after the project.

Tentative Budget:
David Sunding: 2 months ($15,000)
David Zilberman: 1 month ($10,000)
Janis Olmstead: 1 month ($10,000)
GSRs (2): 2 months full time, 8 months half time ($33,000)
Costs (travel and supplies): $2,000
Indirect Costs (11%): $7,700
Total Budget: $77,700

Figure 1: Sensitivity of Investment to Level of Uncertainty